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Reliability Improvement of Distribution System: A Hybrid Approach Based on GA and NN

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Abstract* — Due to high power demand, modern utilities are continuously planning the expansion of the electrical networks. One of the methods used for the expansion of electrical networks is connecting distributed generator (DG) in the distribution system. The main function of DG is to generate power based on the load condition or any fault occurs in the electrical network. By connecting DG in the distribution system, the power demand of the system can be satisfied and also it improves the reliability of the electrical network. The major problem in DG is, identifying the optimal location for fixing DG in the system and also computing the optimal number of DG to be connected in the system. By considering the abovementioned problem, here a hybrid technique is proposed, which includes genetic algorithm and neural network to identify the optimal number & location of DG to be connected in the system. The proposed method also computes the amount of power to be generated by each DG for various load conditions. By connecting DGs, the number of generators in the network increases and so that different generator states are possible for a particular load condition. From the possible generator states, the best state is selected based on some reliability parameters. Here, the reliability parameters that are considered for identifying the best generator states are loss of load probability (LOLP), loss of load expectation (LOLE), expected energy not supplied (EENS) and system expected outage cost (ECOST). The above reliability parameters are computed for different load conditions and also for the optimal number of DG identified using the proposed method. By using this method, the best generator state for different load conditions and also for different number of generators is computed. The result obtained shows the development in system reliability due to connecting optimal number of DG in the system.

***Keywords*— Reliability, ECOST, EENS, LOLP, LOLE, DG, Distribution system.**

I. INTRODUCTION

In general, the electric power system comprises a generating system, a transmission system, power substations and the distribution network [1]. The main role of the power generation and transmission system is to provide the power and energy required by the consumers with a certain amount of reliability and quality of service at low cost [2].

Today, the electric power industry all over the world is undergoing substantial changes with respect to structure, function, and regulation [3]. The use of distributed generators (DG) within distribution network has drawn huge attention due to several advantages that small scale generation can potentially provide to power utilities [12]. The distributed generation (DG) has created a new way for the electric power generation [4].

Any power generation that is integrated within the distribution system is called distributed generation [5]. DGs are placed in best possible location in power system planning to help the company to meet both reliability cost and worth requirements [6]. Thus, installing DG in distribution system may have considerable impact on power flow, voltages, and reliability indices, which could be positive or negative. It would be positive if they are properly coordinated with rest of the network [7]. The location of distributed generator in distribution feeders is expected to have an impact on the operations and control of power system, a system created to function with large, central generating facilities [11].

As well, application of DGs has numerous benefits, such as better economy regarding the expansion of large power plants, less environmental pollution, higher efficiency, enhanced quality of electric supply to consumers, reduction of loss in distribution systems, better voltage profile, and releasing of network capacity [13]. Reliability is co-dependent with finances and increased investment is essential to achieve better reliability or even to maintain reliability at current and acceptable levels [8]. Currently, probabilistic approaches are utilized more extensively in power system operations and planning due to the presence of various uncertainties [9]. Loss of load probability (LOLP) is one of the most frequently employed indexes for planning generation capacity [10].

II. RELATED WORKS

Qin *et al*. [14] have investigated the reactive power aspects in power systems reliability evaluation. A technique has been proposed to calculate the load point reliability of power systems with reactive power shortage due to failures caused by reactive power sources namely, generators, synchronous condensers, and compensators. The reliability indices due to reactive power shortage have been defined and were separated with those due to real power shortage. Reactive shortage has been determined using reactive power injection at the nodes with the voltage violation to yield additional information for system planning and operation.

Mohammadi *et al*. [15] have proposed a Particle Swarm Optimization (PSO) based technique for the placement of Distributed Generators (DG) in the radial distribution systems to diminish the real power losses as well as to enhance the system reliability.

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A hybrid objective function has been employed for the best placement of DG. The proposed technique comprises two indices namely, Power Loss Reduction Index and Reliability Improvement Index. The first one deals with power losses in the system whereas the second one considers the effect of DG on reliability improvement of system.

Heydari *et al.* [16] have presented a problem formulation and solution for the placement and sizing of DGs optimally. Their goal is to enhance the reliability indices. The position and size of DGs have been optimized by means of a Genetic Algorithm (GA). Here, IEEE 34 buses distribution feeder has been usedto analyze the ability of the proposed algorithm.

Kansal *et al*. [17] have devised a PSO based approach to identify the best possible size and location for the placement of DG in the radial distribution networks for active power compensation by diminution in real power losses and enhancement in voltage profile. Initially, the optimal size of DG has been computed at each bus using the exact loss formula and then, the best location of DG has been found by means of the loss sensitivity factor. The analytical expression was based on exact loss formula.

Mohammadi *et al*. [18] have discussed the optimal placement of DG unit based on GA. The optimal size of the DG unit has been computed analytically by means of approximate reasoning suitable nodes. Reliability and power loss reduction indices of distribution system nodes have been modeled. GA having a set of rules has been employed to find the DG unit placement. DG units were positioned with the highest suitability index. The benefit of optimal DG unit placement has been revealed via simulation results.

Paliwal *et al*. [19] have proposed a technique to discover the optimal distributed generation allocation for loss reduction subjected to constraint of voltage regulation in distribution network. The system has been further evaluated for increased levels of reliability. Distributed Generator provides additional advantage of increase in reliability levels as suggested by the improvements in different reliability indices namely, SAIDI, CAIDI and AENS. Comparative studies have been conducted and the corresponding results have been exposed.

Shayeghi *et al.* [20] have introduced a hybrid coded genetic algorithm and particle swarm optimization based technique for investigating the optimal generation expansion planning in restructured power system. In addition, independent power producer's contribution and two reliability criteria such as LOLP and EENS have been considered in GEP problem. The proposed approach is a fast technique for computation of reliability criteria and can simply obtain best purchase prices for diverse types of IPP.

III. RELIABILITY IMPROVEMENT OF DISTRIBUTION SYSTEM USING DG

Distribution generator is one of the one of the important process in distribution system, which is now commonly used to improve the reliability of the system. The most important process in distributed generator is identifying the optimal location for fixing DG in the system and also to compute the amount of power to be generated by that DG. By fixing DG in optimal location identified using the proposed method, the reliability of the system increases. Another important thing considered here is identifying the optimal number of DG to be connected in the system. Here genetic algorithm is used to identify the optimal number of DG to be connected in the system, optimal location for fixing DG in the system and also the amount of power to be generated by that DG.

A. *Identifying optimal number, location and power generation of DG using GA*

Genetic algorithm is one of the evolutionary algorithms which is mainly used for optimization process. Normally genetic algorithm consists of five stages namely; generation of initial chromosome, fitness function, crossover, mutation and termination. In genetic algorithm the initial process is generating initial chromosome. The initial chromosome is generated based on the requirement. In the proposed method, genetic algorithm is used to compute the amount of power to be generated by DG and also to identify the optimal location for fixing DG in the system. Now we can see about the process takes place in each stages

i. Initializing chromosome

Initializing chromosome is the most important process in genetic algorithm. Let N be the number of DG to be connected in the system, P_{DG} to be the real power generated by DG, Q_{DG} to be the reactive power generated by DG and these powers are generated within a particular limit. The real and reactive power generating limit is $P_{DG}^{\min} \leq P_{DG} \leq P_{DG}^{\max}$ and $Q_{DG}^{\min} \leq Q_{DG} \leq Q_{DG}^{\max}$. By considering the above limit the real and reactive powers are generated for each DG and the number of chromosomes generated is X. The next process after initializing chromosome is computing fitness function for the above generated initial chromosomes.

ii. Fitness function

The fitness function used in genetic algorithm is to evaluate the performance of the above generated initial chromosome. The fitness function used in the proposed method is total power losses in the system.

$$Fitness = \sum_{i,j=1}^{N} \mathrm{Re}\,al\left[Conj\left(\left(V_m(i)\right)*\left(V_m(j)\right)\right)*Y_{ij}*B\right] \qquad (1)$$

Where, V_m is the voltage magnitude, Y_{ij} is the Y-bus matrix and B is the base MVA value.

Before computing the fitness function the initial process is to compute the real and reactive power flow between the buses. The real and reactive power flow is computed using the equations 2 & 3 respectively.

$$P_i = \sum_{k=1}^{N} V_i * V_k \left(G_{ik} * \cos\theta_{ik} + B_{ik} * \sin\theta_{ik}\right) \qquad (2)$$

$$Q_i = \sum_{k=1}^{N} V_i * V_k \left(G_{ik} * \sin\theta_{ik} - B_{ik} * \cos\theta_{ik}\right) \qquad (3)$$

where, i is the sending end bus,
k is the receiving end bus,
N is the total number of buses,
$V_i \& V_k$ are the voltage at $i \& k$ bus respectively,
θ_{ik} is the angle between $i \& k$ bus, and
$G_{ik} \& B_{ik}$ are the conductance and

susceptance values respectively.

The next process after applying fitness function is cross over operation.

iii. Crossover operation

In genetic algorithm, crossover operation is done based on the crossover rate. Let us consider the crossover rate in the proposed method as C_r. In the proposed method, the genes are crossed based on the crossover rate C_r and so that new set of chromosomes are generated. For that new set of chromosomes, fitness function is applied and the best genes are selected. The next process after applying crossover operation is mutation operation.

iv. Mutation operation

In genetic algorithm mutation operation is used to mutate some genes and generate a new chromosome. Generally mutation operation is done based on the mutation rate and mutation rate consider in our method is M_r. Based on this mutation rate, new set of chromosomes are generated and after generating new chromosome fitness function is applied. The next process is termination.

v. Termination

Termination is the final stage in genetic algorithm. In the termination stage the best chromosomes are selected based on the fitness function. By using this optimal number of DG to be connected in the system and also the amount of voltage and angle to be injected in the system are obtained. The next process after this is analyzing the performance of the proposed method by considering different reliability parameters.

B. Reliability calculation in distribution system

Reliability is one of the most important parameter to analysis the performance of the system. There are different reliability parameter are in literature. Among the different reliability parameters in the proposed method we considered Loss of load probability (LOLP), Loss of load expectation (LOLE), Expected Energy Not Supplied (EENS) and Expected Cost of Interruptions (ECOST). Now we can see the mathematical models used for computing the reliability parameters for distribution system. Initially we see about the mathematical model used for computing LOLP.

1) Loss of load probability (LOLP) : LOLP is one of the reliability parameter to show the performance of the proposed method. Initial process takes place in LOLP is identifying the possible states of power generation. The number of possible states is fully depends on the number of generators connected in the system. The number of possible states is computed using the equation 4.

$$\text{Number of possible states} = 2^n \qquad (4)$$

Where, n is the number of generators connected in the system.

Using the above equation the number of possible states is identified. The next process is identifying the possible states after connecting each generator in the system. The possible states starts from 0 and then from the lowest values, till the end of the values. The

The next process after identifying the possible states is identifying the first outage rate.

$$\text{F.O.R} = U = \lambda / (\lambda+\mu) \qquad (5)$$

Where, λ is the unit failure rate,

μ is the unit repair rate.

After calculating the FOR the next step is calculating the probability for each possible state. The probability of each state is computed using the equation 5.

$$P(X) = (1-U) * P^{I}(X) + U * P^{I}(X-C) \qquad (6)$$

Where, P(X) is the cumulative probability of capacity outage state of X after the unit is added

$P^{I}(X)$ is the cumulative probability of capacity outage state of X before the unit is added

C is the capacity of generating unit added in MW

X be the capacity outage state of a unit in MW

After calculating the probability of each possible state, the next step is

$$LOLP = \sum P(Y) * P_O \qquad (7)$$

Where, Y = Outage > Reserve

Reserve = Installed capacity - Load

P_O is occurrence probability of a particular load

$$P_O = N_O / N_t \qquad (8)$$

N_O is the number of occurring days of that group in observation period of 1 year

N_t is the total number of days in the observation period.

By using the above equations, LOLP is computed and the next reliability parameter we considered is LOLE.

2) Loss of load expectation (LOLE): Loss of load expectation is a numerical measure of the likelihood of failure and does not quantify the extent to which supply fails to meet demand. The mathematical model used for computing LOLE is shown in equation 9.

$$LOLE=LOLP*T \qquad (9)$$

T=360 days, if the load model is an annual continuous load curve with day maximum load

T=8760 hours, if the load model is an hourly load curve.

By using the above equation, LOLE is computed and from the above equation it is clear that the LOLE fully depends on LOLP and time/days. Next reliability parameter we considered is EENS.

3) Expected Energy Not Supplied (EENS) : For bulk power system, the expected value of value energy not supplied is said to be EENS. The mathematical model used for computing EENS is shown in equation 10.

$$EENS = \sum_i \sum_k L_k h_i t_i \qquad (10)$$

where, t_i is the interruption time,

L_k is the load,

h_i is the failure rate

By using the above equation, the EENS is computed. Next reliability parameter we considered is ECOST.

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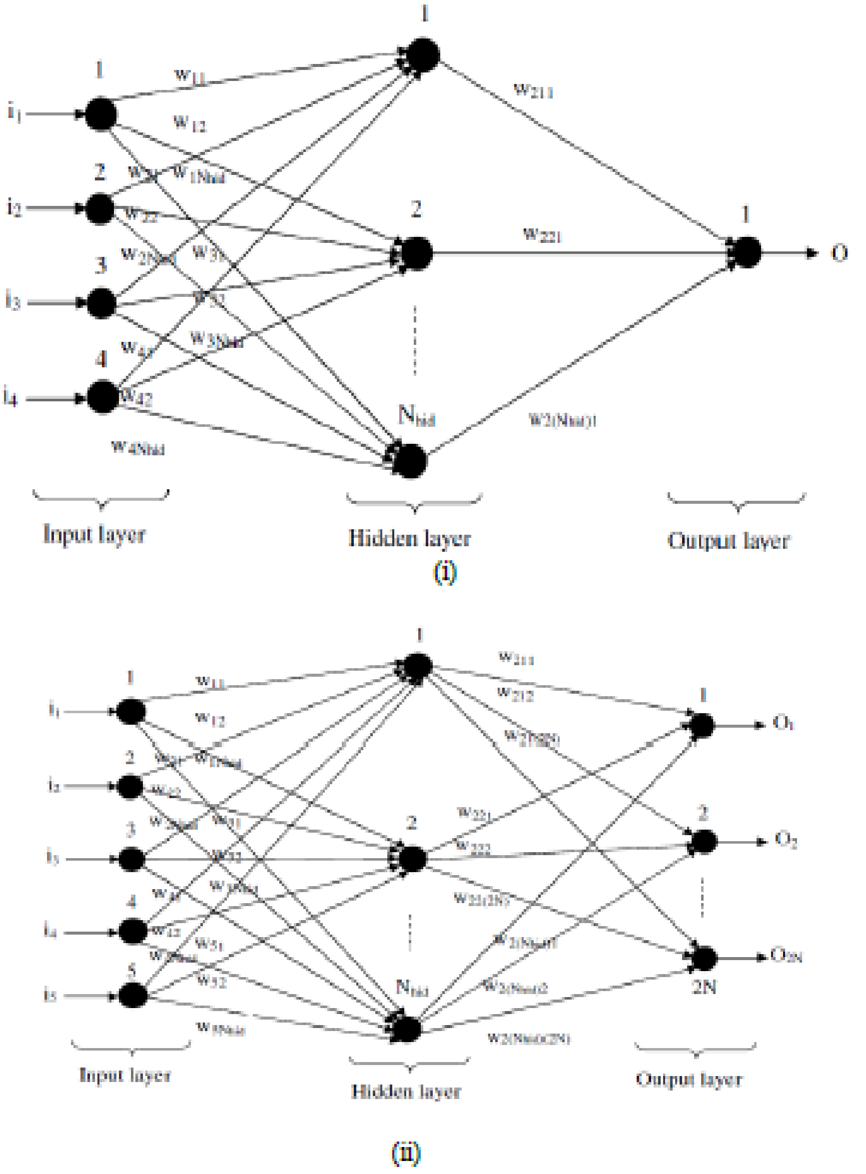
4) Expected Cost of Interruptions (ECOST) : Excepted cost of interruption is said to be the expected cost due to occurring interruptions in the system. The mathematical model used to compute the ECOST is shown in equation 11.

$$ECOST = \sum_i \sum_k L_k \, h_i C_{ik}(t_i) \qquad (11)$$

where, $C_{ik}(t_i)$ is the customer interruption cost with interruption duration t_i.

C. Best State Learning using NN

In this work, we consider two feed forward neural networks to train the best DG parameters that are optimal number and locations of DGs and power to be generated. The use of feed forward neural networks here are to act like a memory to remember the best possible specifications of DG connections under different load conditions. Unlike other works, in this paper, we enable neural networks to relate the reliability parameters and the DG connection specifications so that once the network gets learned well, then the DG connection specifications can be obtained instantly by giving reliability parameters. The structure of considered feed forward neural network is given below.



(i)

(ii)

Figure 1: Neural Network Architecture (i) to determine the optimal number of DGs to be connected in the system and (ii) to determine the optimal location of DGs to be connected and the optimal power to be generated by the DGs

The input and output parametric models of the two neural networks are given as follows

Input Models:

Network 1: $[i_1 \; i_2 \; i_3 \; i_4\,]_1 = [LOLP \quad LOLE \quad EENS \quad ECOST\,]$

Network 2: $[i_1 \; i_2 \; i_3 \; i_4 \; i_5\,]_2 = [LOLP \quad LOLE \quad EENS \quad ECOST \quad N_{DG}^{opt}\,]$

Output Models:

Network 1 : $o_1 = N_{DG}^{opt}$

Network 2: $[o_1 \; o_2 \ldots o_N \; o_{N+1} \ldots \; o_{2N}\,] = [s_1 \, s_2 \ldots s_N \;\; p_1 \, p_2 \ldots p_N\,]$

where, $s_i \in [0,1]$: $1 \le i \le N$ and $p_i \in [\,p_{DG}^{\min}\,,\, p_{DG}^{\max}\,]$.

The network training is carried out using Back Propagation Algorithm (BP) [21] whereas in testing, the first neural network gets the first place. Once it is tested to aware about the number of DGs to be connected, it is added with the reliability parameters to get the details of locations at which the DGs to be connected and the power to be generated in them.

IV. RESULTS AND DISCUSSION

The implementation of the proposed method is done in MATLAB 2011 and IEEE 30 bus system is utilized for testing the performance of the technique. The standard IEEE -30 bus system [22] [23] is shown in Figure 2

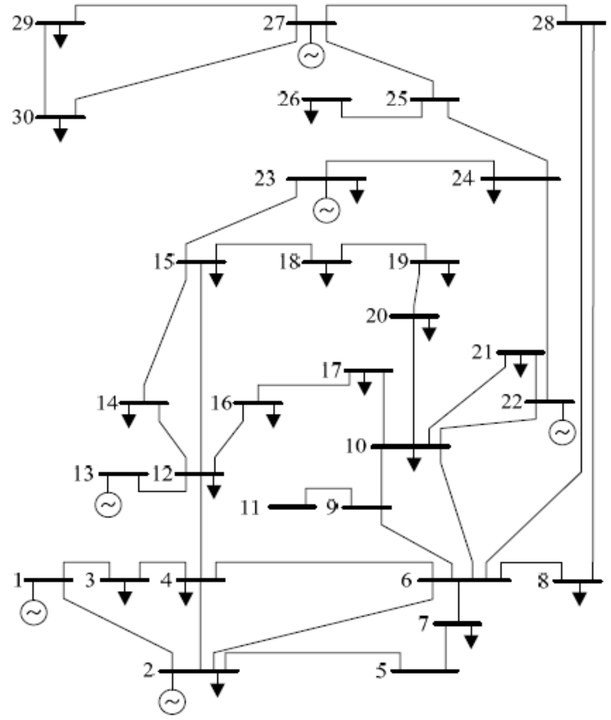
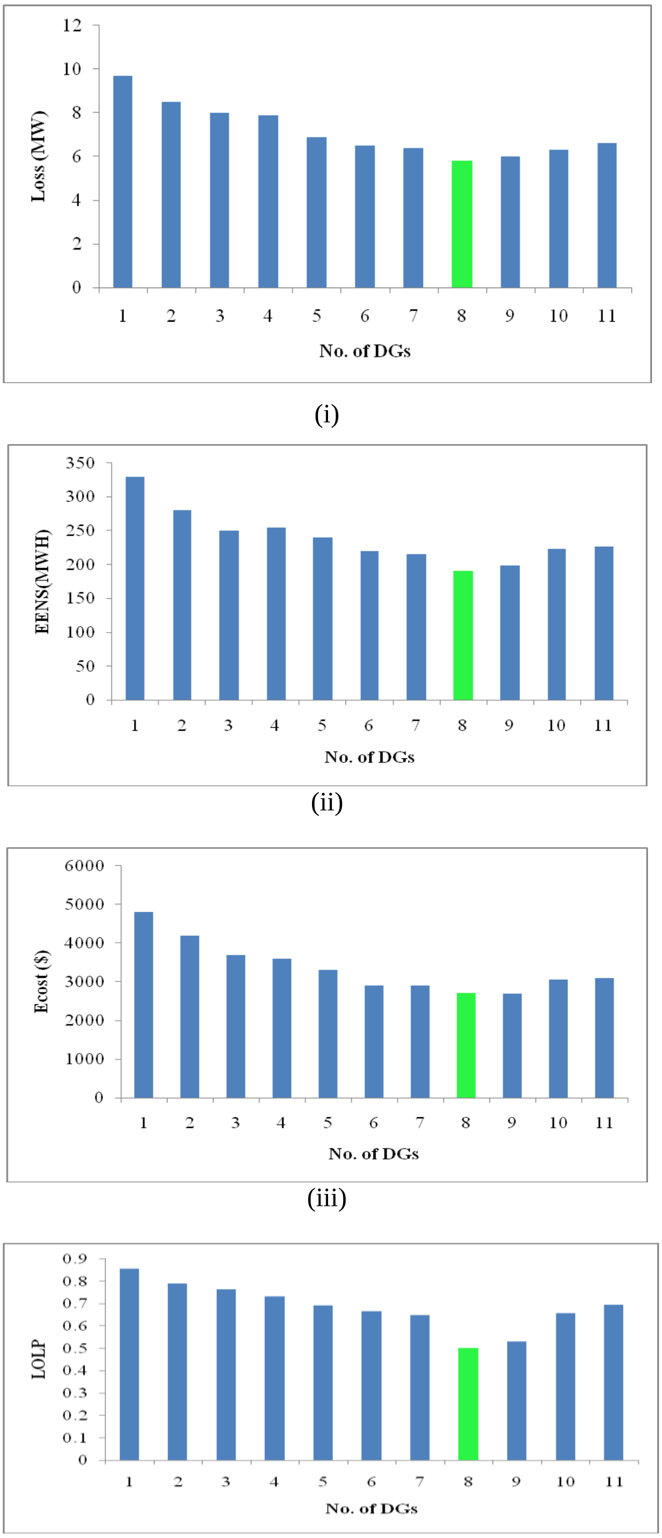


Figure 2: IEEE-30 Bus System

Table I: Performance Of The System In Terms Of Loss And Reliability Parameters With And Without Dg Connections

Sl. No.	PerformanceParameters	Without DG	With DG	Reduction (in %)
1	LOLP	0.00906	0.00501	44
2	LOLE (in %)	0.91	0.49	46
3	EENS (MWh)	340	191.8215	44
4	ECOST ($)	4920	2694.8816	45
5	Total power loss (MW)	10.563	5.738	46

Discussion: From Table 1, it can be seen that without connecting DG i.e. without applying the proposed method, the total power loss is about 10.563 MW, however when the DGs are connected to the system as per the proposed method's outcome, the total power loss was minimized to 5.739 MW. Thus reduced loss is just 46% of the uncontrolled loss. Similarly, the reliability parameters, EENS is 340 MWh and 191.82 MWh, when DGs are not connected and connected respectively, which provides 44% advantage over the system without DGs, LOLP exhibit a probability rate of 0.906 and 0.501, whereas LOLE is 91% and 49%, when DGs are not connected and connected as per the proposed method suggestion, respectively. ECOST is about 4920$ and 2695$, when DGs are not connected and connected respectively. This in turn clearly shows that the system with proposed DG connection offers 44%, 46%, 44% and 45% more reliable that the system without any DG connection in terms of LOLP, LOLE, EENS and ECOST, respectively. The effect/ drawbacks of not following the proposed DG connections in terms of loss and reliability parameters are illustrated in Figure 3.



(i)

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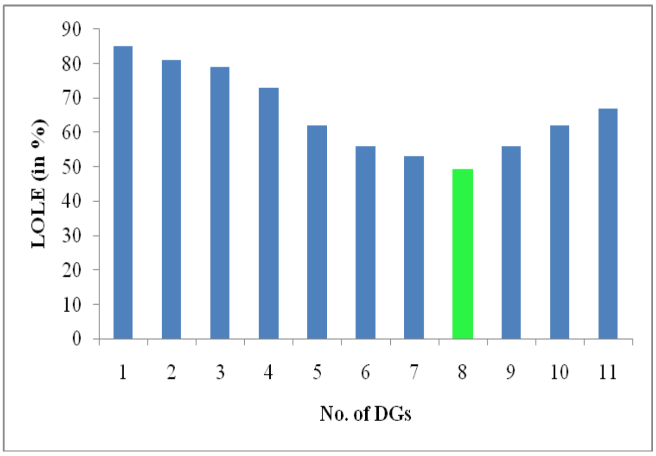

(v)

Figure 3: Performance of Proposed DG connections in terms of (i) Total loss, (ii) EENS, (iii) Ecost, (iv) LOLP and (v) LOLE

Discussion: From Table shows the system benefits when DG is connected and not connected whereas Figure 3 shows the advantages of maintain proposed DG connections over the other DG connections. In other words, we experiment the system reliability and losses by keeping the proposed DG connections and then by connecting all the possible DG connections. From Figure 3, it can be easily understood that the proposed DG connection offers less loss and high reliability when compared to the other alternative connections.

V. CONCLUSION

In this paper, a hybrid methodology for finding optimal DG connection specifications is proposed to operate the power system with minimal power loss and with high reliable power transmission and distribution. The methodology was tested in IEEE-30 bus system to analyze the performance of providing optimal DG connection specifications. A sample connection specification given by the methodology had proved the performance in terms of losses and reliability. Firstly, the analysis was carried out by making the proposed DG connections and without making the DG connections. It showed a wide variation in the loss and reliability i.e. nearly 50% loss was reduced when the proposed DG connection was made, whereas nearly 50% more reliability could be accomplished when the proposed DG connections was against without any DG connections in the system. Secondly, the analysis was carried out between the proposed DG connections and alternate DG connections in which again the wide range of performance deviation could be seen. This time the performance deviation was about nearly 20-40% deviation i.e. the proposed DG connection enables the system to operate in 20-30% less loss and in a more reliable way. These are all the observations, which we got from the total loss calculations and calculation of reliability indices such as LOLP, LOLE, EENS and ECOST and finally it was proved the proposed DG connection specifications outperform the alternate DG connections.

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